Fingernail-Mounted Display of Attraction Force and Texture

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Abstract. The paper studies two methods of haptic. One is an attraction force display that can induce attraction force by a cyclic movement of a weight with asymmetric acceleration. Another is a texture display that induces a sensation of texture by giving off vibration while a subject traces a finger over a flat surface. In this paper, we propose a novel design that can induce both attraction force and texture feeling. The prototype consists of four vibration motors, which are controlled to generate asymmetric acceleration and vibration. The device is evaluated by experiments.

Keywords: haptic interface, tactile display, pseudo-attraction force, pseudo-texture.

1 Introduction

We have developed devices adopting a pseudo-texture display [1] and a pseudo-attraction force display [2] in the past. These techniques focused on the ability to use vibration, and later a prototype fingernail-mounted display [3] was constructed to achieve the above two functions using four vibration motors. This device recreates the target vibration wave shape. However, the device could not provide pseudo-attraction force or pseudo-texture because it failed to achieve the required performance at a practical output torque and frequency.

In this research, we propose a new mechanism that solves these problems and discuss the development of a device that can provide pseudo-attraction force and pseudo-texture.

2 Fingernail-Mounted Attraction Force and Tactile Display

2.1 Tactile and Attraction Presentation Technique

When a small mass in a handheld device oscillates along a single axis with asymmetric acceleration (strongly peaked in one direction and diffuse in the other, Fig. 1), the person holding it typically experiences a kinesthetic illusion characterized by the sensation of being continuously pushed or pulled by the device. Furthermore, when the rotation speed of weights is 5–9 Hz, people tend to perceive pseudo-attraction force easily.

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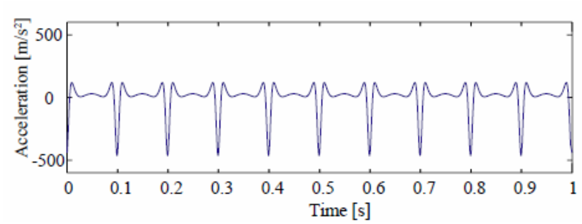

Fig. 1. Ideal acceleration for presenting pseudo-attraction force

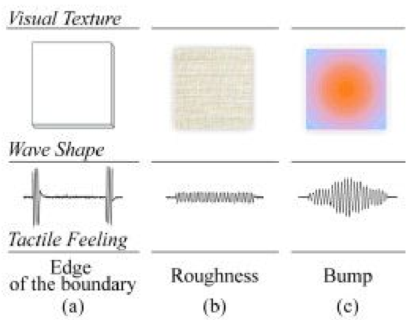

Fig. 2. Vibration waveform for texture presentation

On the other hand, if the vibratory stimulation is given when the object is traced by the finger, it has been shown to cause a pseudo-texture (Fig. 2) in the finger pad. This stimulus needs to have a vibration frequency of 100–200 Hz.

In this research, we aim to present these two types of vibration stimuli in a single device. The vibrational pattern is generated by controlling the phase of an eccentric weight's rotation.

2.2 Generating a Vibration Pattern by Phase Control

Four eccentric weights are attached to one fingernail, where two weights rotate clockwise and the other two rotate counterclockwise, with all weights rotating at the same frequency. If there were no phase control, the rotation of the eccentric weights would make a random vibration. However, when the weight of each phase in the same rotational direction shifts 180 degrees, the weights' centrifugal forces cancel each other out, thus producing a non-vibration state (Fig. 3 (a)). Moreover, centrifugal forces other than the element of the symmetrical axis can be negated by turning to the line symmetry the weight that rotates in the opposite direction. Under such a condition, when the weight rotates, a pseudo-attraction force can be presented in an arbitrary direction (Fig. 3 (b)). Furthermore, when the weights stop and are then driven by the high frequency of the non-vibration state, a vibration is generated for the current pseudo-texture (Fig. 3 (c)).

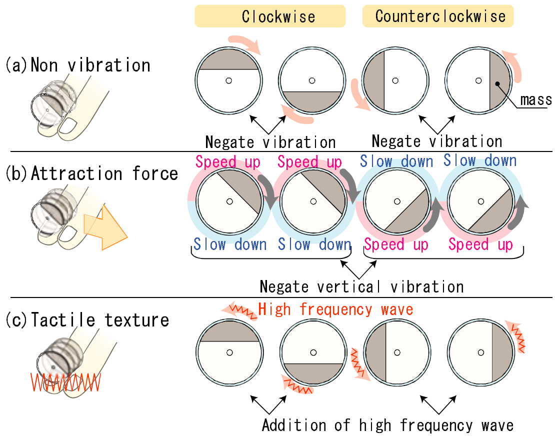

Fig. 3. How to generate a vibration pattern

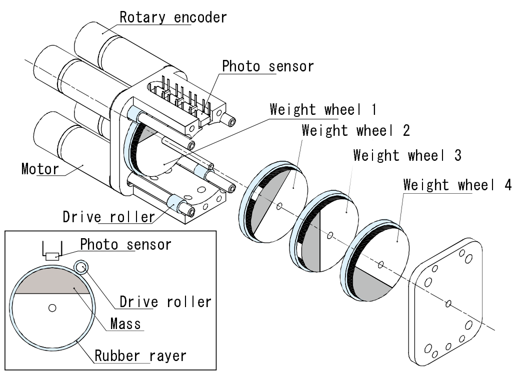

Fig. 4. Proposed fingernail-mounted display mechanism

2.3 Prototype Display

The previous fingernail-mounted device [3] was built with vibration motors (Namiki Precision Jewel, 4CR-1002W-07). This device can operate in a narrow band of vibration frequency. Moreover, the weak torque of the motor and the motor's vibration resonate with each other, causing a problem that could not be controlled by phase.

Therefore, in this paper we propose a friction drive mechanism to drive the eccentric weights (Fig. 4). This mechanism is designed to achieve large drive torque and wide-band vibration frequency. The motor used is the Maxon RE8, where the reduction gear ratio is 6:1, the radius of the eccentric weight is 18 mm, and each weight is 2 g. The size of this device is 20 × 25 × 42 mm, and its mass is 30 g. The positions of the weights were found by a photo sensor, and the rotary encoder's microcomputer (Microchip Technology, dsPIC33FJ128) conducted feedback control.

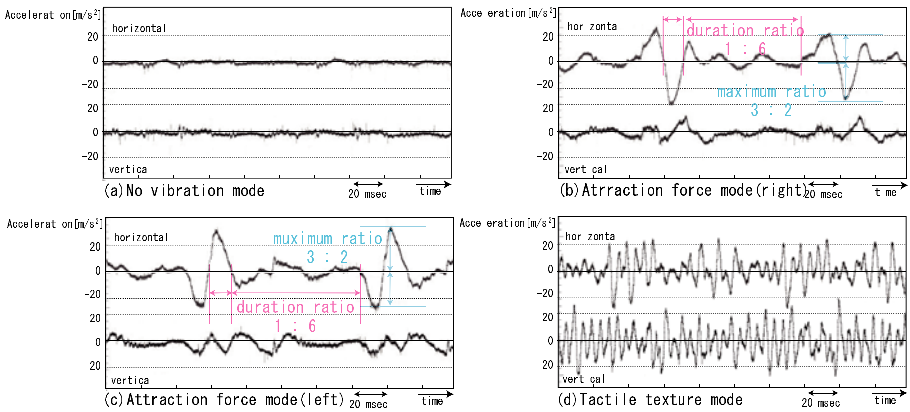

Fig. 5. Acceleration of vibration waveform

3 Performance Evaluation of Prototype Device

3.1 Acceleration of Vibration Waveform

Figure 5 shows the display placed on the fingernail, where an accelerometer (Freescale Semiconductor, MMA7361L) measures the vibration of the display. In this case, the motor is driven at 10 Hz and the vibrational frequency used to present the texture is 100 Hz. The non-vibration mode in Fig. 5 (a) nearly cancels out the horizontal and vertical acceleration. Figure 5 (b), (c) shows the attraction force mode, where the duration ratio is 1:6 and the maximum ratio is 3:2. As shown in Fig. 5 (d), a vibration of 100 Hz is generated.

3.2 Perceptual Characteristics

In order to confirm the existence of a pseudo-attraction force created by the display, the subjects wore the display on a fingernail, and a vibration stimulus was applied by the display for the subjects. The subjects were four adult men, all of whom were right-handed.

3.2.1 Experiment of Pseudo-attraction Force Perception

The nail-mounted display was worn on the right hand's index and middle fingers. First, the display worked in the non-vibration mode. Next, the display worked in the attraction force mode (to right or to left), and the stimulus was presented for three seconds. After the presentation, the display again worked in the non-vibration mode. The stimulus was presented 10 times each in the right and left directions. The stimuli were presented in random order. Subjects responded to the perceived direction of the attraction force by selecting from three choices: "Right," "Left," or "I do not know."

Table 1. Correct answers for perceived direction of pseudo-attraction force (percent)

Subject	A	B	C	D	(Average)
Percentage of correct answers	90%	95%	80%	100%	(91%)

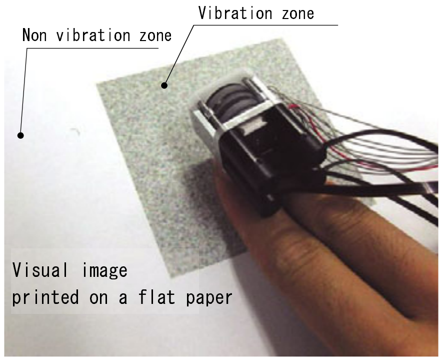

Fig. 6. Conditions for presenting pseudo-texture

Table 1 shows the results of correct answers for the perceived direction of pseudo-attraction force. The introspective reporting by subjects of “felt my fingers pulled” is listed.

3.2.2 Experiment on Pseudo-texture Perception

The subjects traced over flat paper with the printed visual texture by their fingers (Fig. 6). If the subject’s fingers traced in the non-vibration zone, the display worked in the non-vibration mode; similarly, if the subject’s fingers traced in the vibration zone, the display worked in the texture mode. Trace speed and direction of subject's finger are unrestricted, and tracing was done for 30 seconds. After the tracing, subjects were given a choice as to whether they felt the texture, the vibration, or nothing.

As a result, all of the subjects felt the texture. The introspective reports of subjects included “felt like the friction grew on the visual texture” and “felt like the finger dropped down when it moved from vibration zone to non-vibration zone.”

4 Discussion

From the experimental results on the perception of pseudo-attraction force, all subjects achieved a rate of correct answers higher than 80%. This indicates that traction was presented. Moreover, the subjects only gave incorrect answer in the case where the left attraction force was presented at the right side. We can conclude that the display's center of gravity moved to the right, caused by the distributing cable. To solve this problem, a soft and light cable should be adopted to prevent it from influencing the posture of the device.

The previous pseudo-attraction force display [1] could provide attraction force in only one direction. To provide the attraction force in any direction, the display needs to physically rotate. However, the proposed display can provide attraction force in any direction by itself, which is the major advantage of this display.

Consequently, the maximum ratio of the proposed display’s acceleration waveform is only 3:2, significantly smaller than the ratio of 3.5:1 achieved by the previous display. The relationship between maximum ratio and perception of acceleration force has not been discussed so far. However, the proposed display can provide pseudo-attraction force. Accordingly, while the previous display provides attraction force for the arm, the proposed display can provide attraction force for the finger. In the future, it will be necessary to examine the frequency, duration ratio, and maximum ratio for fingernail-mounted devices.

From the experimental results of the perception of pseudo-texture, all subjects were able to feel the texture on their finger pad. This means that the proposed display is able to provide pseudo-texture. The previous display [2] was able to vibrate enough gain only near the resonant frequency by using a voice-coil-type tactor, but the proposed display is able to vibrate at any frequency. This means that the proposed display is able to provide more texture patterns of stimulation than the previous one. Therefore, in the future we need to find out what new textures the proposed device is able to provide.

5 Conclusion

In this paper, we proposed and developed a fingernail-mounted display to utilize pseudo-attraction force and pseudo-texture. Furthermore, perceptual experiments were conducted using the proposed device. As a result, the proposed display was able to provide pseudo-attraction force and pseudo-texture.

In the future, we would like to investigate the parameters of the proposed display that are effective in providing the pseudo-attraction force and the pseudo-texture. In addition, the display will be made more lightweight and compact.

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